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FUNDAMENTAL FACTORS INFLUENCING THE BEHAVIOUR
OF PAPER PRODUCTS UNDER EXTREME CLIMATIC CONDITIONS

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FUNDAMENTAL FACTORS INFLUENCING THE BEHAVIOUR OF
PAPER PRODUCTS UNDER EXTREME CLIMATIC CONDITIONS

H.G. Higgins¹ and A.J. Watson¹

INTRODUCTION

Climate and Economic Development

1. The lack of economic development in many parts of the world is related partly to the prevailing climate, which may constitute a severe disability in respect to human health or comfort or which may restrict the practice of agriculture or forestry. Even when factors such as soil, terrain, mineral resources, access, and the social and political structure favour industrial development, it may be retarded if its circumstances are not those engendered by an equable climate. This may apply particularly to those industries processing biological material. The transitions from a traditional craft to a large-scale industry, and from batch to continuous production introduce many new problems which may be aggravated by prevailing climatic conditions.

Use of Paper in Less Developed Areas

2. Although papermaking originated in China and gradually spread to the Middle East and then to the West where it became a traditional craft, it has become a large-scale industry only in comparatively recent times. Like many other industries which involve the processing of a raw material, it has flourished mainly in temperate regions and consequently the practical problems of manufacture and use under the more extreme climatic conditions are understood in a relatively imperfect way. However, a considerable amount of information is available on the scientific level which allows us to predict with some degree of confidence the response of paper and other cellulosic products to climatic extremes. In this connection we are concerned particularly with countries experiencing a warm, moist climate, such as some of the newer nations of Africa, and with those experiencing a very hot, dry climate, such as the countries of the Middle East.

3. The use of paper for many purposes, such as printing on modern machines, requires higher specifications than was formerly the case in respect to such properties as strength and dimensional response to humidity variations, and the extreme conditions of environment would tend to accentuate any difficulties which might arise in the

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TABLE 1

CLASSIFICATION OF PAPER PROPERTIES:Structural
MechanicalOpticalElectrical
ChemicalFACTORS INFLUENCING PAPER PROPERTIES:EnvironmentRelative humidity
TemperatureInter-Fibre Bonding

Hydrogen bonds

Additives

Fillers, Sizes, Dyes:

Fibre PropertiesDimensions
Flexibility
Crystallinity
Swelling propensity
D.P. of carbohydrates
Lignin content
Hemicellulose
content
typeFormation

(homogeneity)

Wet PressingDrying TensionsChemical TreatmentCalenderingCoatingFACTORS INFLUENCING FIBRE PROPERTIES:Biological OriginSpecies, Age,
Locality.Pulping MethodsBleachingDrying and Re-
wettingBeating

process of manufacture or subsequent treatment. Thus the extension of industry, literacy, hygiene, technology and science to the less developed countries will tend to give rise to new problems in the paper industry, and at such times and places as could make their solution difficult unless a clear understanding be gained from the outset of the factors influencing paper behaviour. At relatively low levels of industrialization it is not to be expected that facilities for controlling temperature and humidity will be readily available in paper mills, printing works etc..

Factors Influencing Paper Properties

4. The main groups of paper properties, the factors influencing them and the way in which fibre properties may have been determined by the beginning of the actual papermaking stage, are indicated in Table 1. The paper properties are determined in a complex way by the various factors indicated, but we shall be concerned here only with the effects of environment and in particular of relative humidity and temperature.

EFFECTS OF HUMIDITYMechanical Properties

5. The way in which strength properties vary with moisture content (and hence with relative humidity) is quite well known and has recently been summarized by Brecht². Those properties depending

² Brecht, W., The effect of structure on the major properties of paper behaviour with fluids. In "Formation and Structure of Paper" (Proc. Oxf. Symp. 1961) Brit. Pap. Board Makers Assoc. Lond.

mainly on inter-fibre bonding, such as breaking load and bursting strength, pass through a maximum in the vicinity of 5 per cent. moisture content, whereas other properties, such as tearing strength, breaking strain and folding endurance, may have a maximum value at considerably higher moisture contents. The response of the various mechanical properties to relative humidity changes may vary with the composition of the pulp, its processing, and the pulping method; the chemical composition will influence the equilibrium moisture content attained. The general effect of increasing moisture content on the stress-strain curve of paper³ is to decrease the stress at a given extension.

6. The response of paper to changes in moisture content depends to some extent on the nature of the fibrous elements in the sheet, so that factors such as fibre length and cross-sectional dimensions may have a significant effect. The development of mechanical properties on drying depends on the composition and processing of the pulp. Thus the tension which develops in paper made from unbeaten pulp increases sharply when the moisture content falls below about 30%, but, after air-drying, the maximum tension attained in this case will not surpass that in a paper made from very highly beaten material dried only to a moisture content of about 50%.⁴

Dimensional Stability

7. Dimensional stability is a factor of paramount importance in many paper applications, for example multi-colour printing and punch card systems. Dimensional instability may lead to a variety of difficulties in manufacture which are usually referred to as "curl" and "cockling". These effects have been studied in considerable detail by Gallay and co-workers.⁵

8. The basic finding in respect to dimensional stability is that the expansion is proportional to the change in moisture content,⁶ but that the factor of proportionality depends on various influences.² One of the most important of these is the degree of beating, both the amount and rate of shrinkage on drying having been found to increase with beating.⁴ The type of pulp has a smaller effect than beating, but is nevertheless significant. Brecht² has found that the rate of expansion, on moistening, in a series of chemical and semi-chemical pulps does not vary greatly with yield in the range 25-65% R.H., but in the range 65-90% the rate was found to decrease with increasing yield, pulps with higher lignin content reacting more slowly. Groundwood has a much lower expansion for a given moisture uptake than other types of pulp, presumably owing to poorer bonding of its lignified and rigid fibres; account should also be taken of the fact that the sorption isotherm will depend on pulp composition.

³ Higgins, E.G., The structure and properties of paper - IX Some Critical problems. Appita, 12, 1-24 (1958).

⁴ Higgins, E.G., Goldsmith, V., and Harrington, K.J., The structure and properties of paper. IV. Drying tensions and dimensional changes in eucalypt kraft papers. Aust. J. Appl. Sci., 6, 496-510 (1955).

⁵ Glynn, P., Jones, H.W.H., and Gallay, W., Drying stresses and curl in paper. Pulp and Paper Mag. Can., 62, T39-T48 (1961).

⁶ Rance, H.F., Effect of water removal on sheet properties. Tappi, 37, 640-654 (1954).

9. The orientation of fibres in the sheet, or the degree of anisotropy, is also of significance for dimensional stability, the expansion being considerably less in the direction of fibre orientation. The higher expansion in the cross-direction can be related to the well-known large lateral expansion of fibres (and of wood); very small effects are observed in the longitudinal direction. Differences in fibre orientation are of great significance in the development of curl, as has been shown by experiments in which the differential between the speed of the wire, and the speed at which the fibre suspension meets the wire, is varied. The non-uniform fibre orientation through the thickness of the sheet is the basic cause of curl,⁵ but by increasing the degree of anisotropy on the wire side, the non-uniformity in the vertical direction is increased. Curl may also occur when changes in atmospheric humidity take place on only one side of the paper.

10. The significance, in the present context, of these and many other similar observations, is that the difficulties encountered under temperate conditions are apt to be magnified under extreme climatic conditions if the prevailing range of humidity is greater than that normally experienced, if the magnitude of the effect under the prevailing conditions (either at high or very low humidity) is greater than it is under more normal conditions, or if the product has been manufactured elsewhere and is subjected to the extremes of humidity and temperature without a proper period of conditioning.

Biological Effects

11. Biological attack occurs principally under conditions of combined high temperature and humidity, such as occur in many tropical countries. Fungal activity may lead to discolouration and staining, and in more extreme cases to weakening of the paper. These effects may be enhanced by the presence of organic materials such as starch or casein in coated paper. Consideration can be given to the use of fungicides to reduce attack, but great care needs to be taken to avoid the use of highly toxic materials, such as phenyl mercuric acetate, for purposes where the product may come into contact with food or in other situations where the toxicity may not be realized by inexperienced people.

EFFECTS OF TEMPERATURE

Chemical Changes

12. Serious chemical changes, such as oxidation, take place very slowly in cellulosic materials at terrestrial temperatures, even at the extremes likely to be encountered in tropical arid zones. However, these changes may be accelerated by the presence of non-cellulosic polysaccharides, moisture etc. The combined effects of temperature and humidity, for example in sponsoring drying of the material, may be quite serious, leading to embrittlement and loss of strength. Degradation is likely to be accelerated by ultra-violet or visible light which may, in the presence of oxygen, give rise to functional groups which will cause discolouration.

Fibre Type

13. These changes will depend on the nature of the fibre to a

large extent. Cotton by virtue of its purity and relatively high crystallinity, is not affected by processes of degradation to the same extent as many wood pulps in which hemicellulose and small amounts of lignin may still be present, and in which the proportion of the amorphous material is greater, thus providing higher accessibility for chemical attack.

Pulping and Bleaching

14. The amount of lignin and hemicellulose remaining in the fibre depends on the method of pulping and its severity in any particular case. In order to provide maximum stability to chemical degradation under extreme temperatures, efficient washing out of the pulping liquor should be effected, as the retention of cooking and bleaching chemicals will tend to sponsor oxidation, perhaps over a long period. It might be expected that the high-yield pulps would have a lower resistance to ageing than the more highly purified pulps. Sulphate pulps are reputed to have better ageing resistance, both in respect to strength and colour, than sulphite pulps⁷. Groundwood often exhibits relatively poor ageing resistance, and where newsprint is required for archives, this may be a serious disadvantage, unless special editions are printed for this purpose on paper of higher quality.

RESTRICTIONS ON USE UNDER EXTREME CONDITIONS

Packaging and Wrapping Materials

15. In extremely wet climates, or under conditions where condensation is likely, many conventional packing and wrapping papers may be rather unsuitable for use unless special precautions are taken to provide them with adequate wet strength. Another factor to be considered is the moisture vapour permeability of the wrapping papers, which may have to be lower under extremes of humidity than that normally considered adequate for temperate climates. These difficulties can usually be overcome by careful attention to the most suitable grades of product for use in the particular situation, but they do impose restrictions on the indiscriminate use of packaging and wrapping materials on the basis of their market availability.

Printing and Writing Papers

16. As mentioned above, precautions against changes in dimensions consequent upon humidity fluctuations are essential for printing operations, and unless high specifications are adhered to considerable difficulties are likely to be encountered in regions with extreme climates. Coated papers may provide greater stability and adequate printing and writing surfaces, but the advantages of specific coatings must be weighed against the enhanced risk of biological attack when the humidity is high.

Photographic Papers

17. The coatings used for photographic papers provide excellent nutriment for micro-organisms under conditions of high humidity,

⁷ Giertz, H.W., A comparison between sulphate and sulphite pulp. Svensk Papperstidn. 56, 893-899 (1953).

and precautions are usually taken to ensure that such papers are stored in the presence of a desiccant. Another geographical hazard, not strictly climatic, is the high level of radioactivity in various parts of the world; considerable difficulties have been reported in respect to the clouding of photographic papers when the pulps have been manufactured in regions where the process waters have been contaminated by fall-out.

TREATMENTS TO EXTEND UTILIZATION

Sizing and Coating

18. Sizing can reduce dimensional changes, but with starch or gelatine sizes the biological hazard remains unless fungicides are incorporated. With rosin alum sizes, this hazard is reduced. The use of high wet strength papers represents another method of extending utilization; various synthetic resins may be used for this purpose. For coated papers which are to be used under extremely high humidity, materials other than casein, with its susceptibility to biological attack, should be considered.

Chemical Modification

19. Dimensional stabilization of paper has been attempted by cross-linking with formaldehyde and other reagents,⁸ and by reducing the hydrophilic nature of the cellulose by acetylation.⁹ These treatments, although expensive, may find some application to papers to be used under extreme conditions. Another approach to the rendering of paper more stable is the work now being done on grafting polymeric materials to cellulose.¹⁰ Any reduction in the hydrophilic nature of the material should be accompanied by a corresponding improvement in dimensional stability. Plastic coated papers may also find increasing use under stringent conditions.

Choice of Raw Material

20. It is to be expected that materials of relatively high resistance to chemical degradation and relatively low response to swelling by water will find a greater use in extreme than in temperate climates. These properties will, in general, be possessed by natural fibres other than wood and by carefully purified wood pulps. However, economic factors would have to be considered before these types of material were preferred, and a compromise effected between the physical properties required.

⁸ Stamm A.J., and Cohen, W.E., Swelling and dimensional control of paper. Appita, 10, 346-393 (1956).

⁹ Stamm, A.J., and Beasley, J.N., Dimensional stabilization of paper by acetylation. Tappi, 44, 271-275 (1961).

¹⁰ Schwab, E., Stannett, V. and Hermans, J.J., Grafting on to cellulose and cellulose fibres. Tappi, 44, 251-256 (1961).